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Open Access Wind Tunnel Measurements of a Downwind Free Yawing Wind Turbine

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Open Access Wind Tunnel Measurements of a Downwind Free Yawing Wind Turbine

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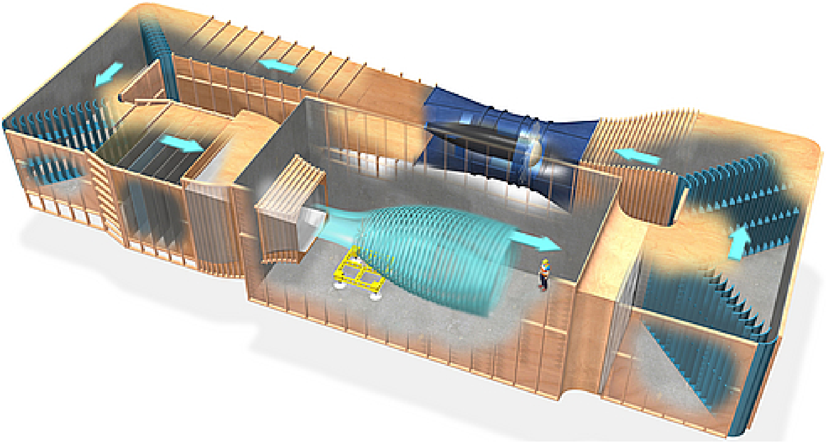
Department of Wind Energy

Outline

- Short overview of the experimental setup
- Limitations
- Results: thrust and estimated power coefficients
- Results: free yaw response
- Conclusions and future work recommendations

The TU Delft Open Jet Facility

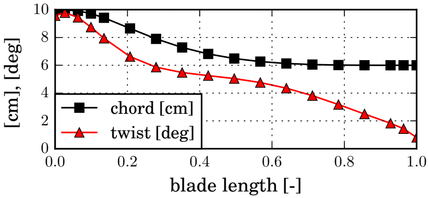
- Wind speeds: 3 - 35 m/s (wind force 11, 70 knots)
- 500 kW fan
- 2.8m by 2.8m exit nozzle

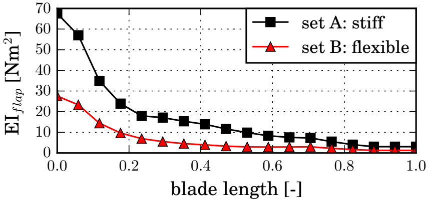


Turbine Dimensions

- Theoretical rotor aerodynamic performance (ignoring flexibility):
  - 280 W at 450 RPM and 11.4 m/s
  - $C_{P_{max}} = 0.36$ at TSR=6 (tip speed ratio)
- Rotor diameter: 1.60m
- Blade root radius: 0.245m
- Blade length: 0.555m
- Tower length: $\approx$ 2m

Blade Aerodynamic Design





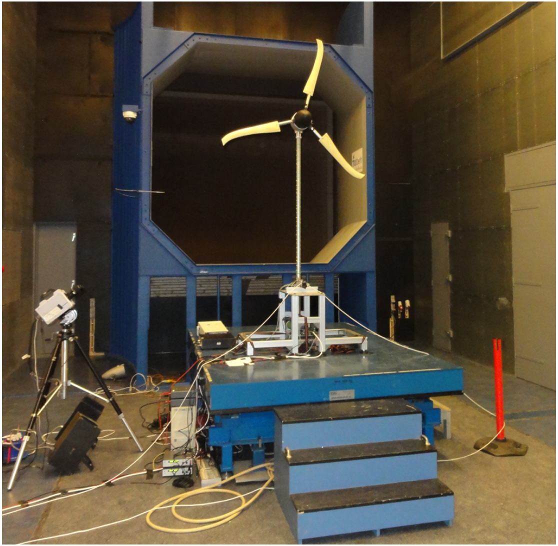
	region	t/c	Re_{design}	Re_{data}	$C_{L_{max}}$
NREL S823 [14]	inboard	21%	$4e5$	$1e5$	1.184
NREL S822 [14]	outboard	16%	$6e5$	$2e5$	1.100

Table: Blade aerofoils and corresponding key parameters.

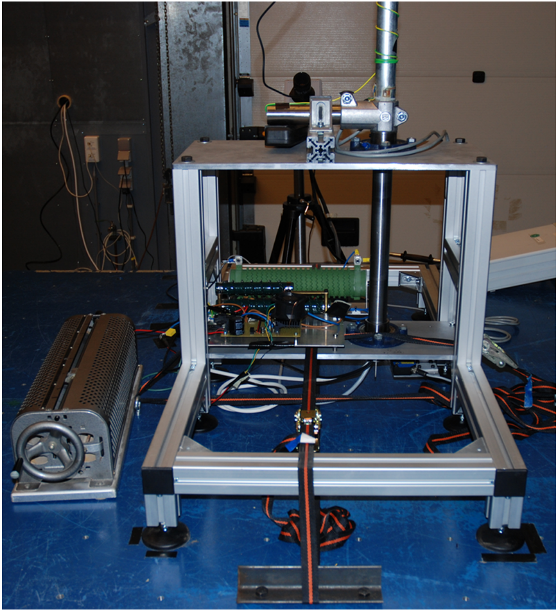
Aerodynamic characteristics are taken from the UIUC LSAT database [15].

Test Setup Overview

- Accelerometer tower top
- Wired data acquisition
- Free yawing (tower base), control with wire
- PM generator, no active torque control
- Blades made from injected PVC foam, internal glass fibre sandwich stiffener
- Rotor speed measurements
- Tower base strain FA, SS
- Blade strain (flapwise), wireless data acquisition
- Yaw angle (laser distance)



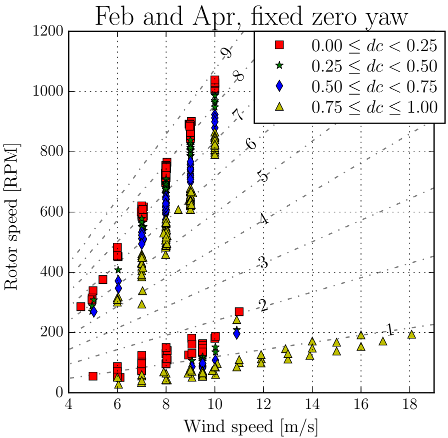
Tower Support Structure

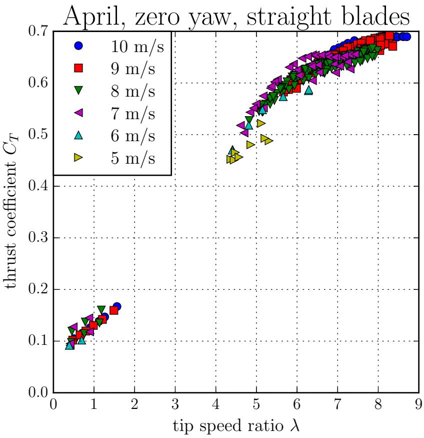


Limitations

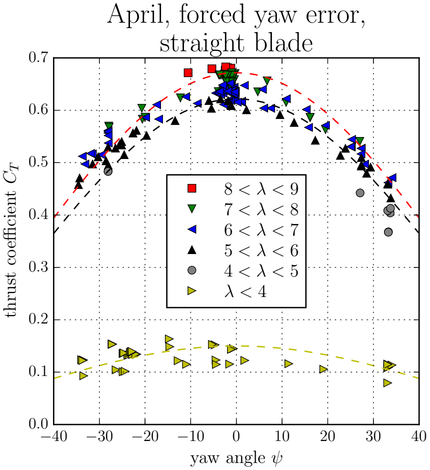
- No active rotor speed control.
- Limited generator torque range.
- No accurate mechanical torque measurement.
- No yaw moment measurement.
- Blade flap-wise strain gauge measurements affected by centrifugal forces.
- Rotor mass imbalance.
- Not so accurate pitch settings (± 1 deg), small pitch and cone angle imbalance.
- No accurate aerodynamic performance characteristics of the rotor (3D-corrected lift, drag and moment coefficients, blade root vortex).
- Electrical losses in the system (generator, wiring, PWM, dump loads).

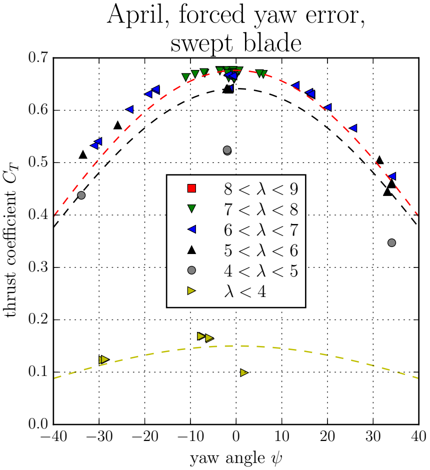
Results - Performance Overview and Thrust Coefficients





Results - Thrust Coefficients as Function of Yaw Angle





Positive yaw angle Ψ means that the blade moving upwards is closer to the wind

Estimating Generator Torque

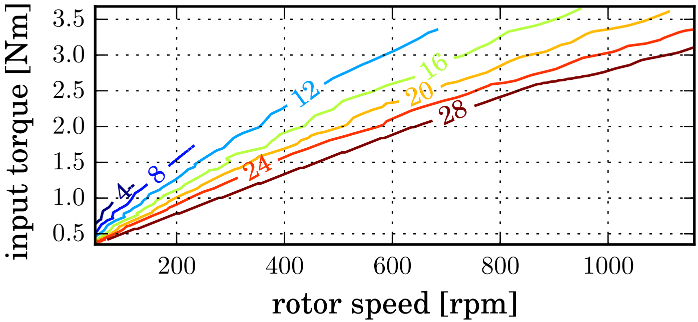
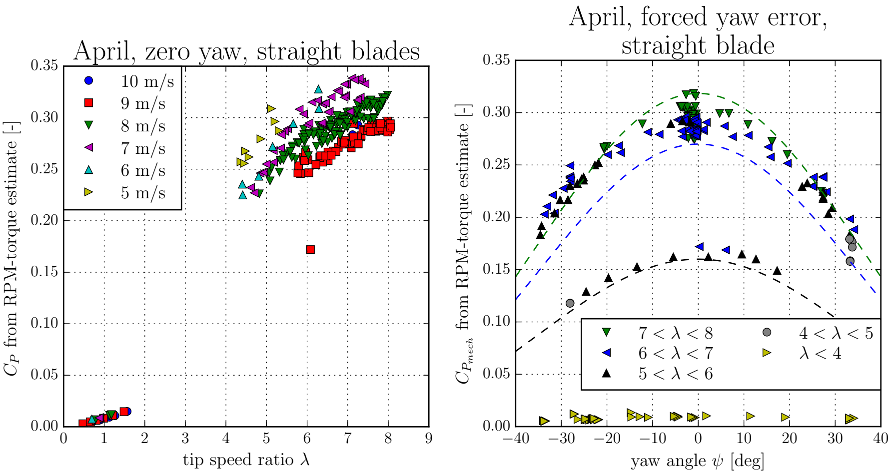


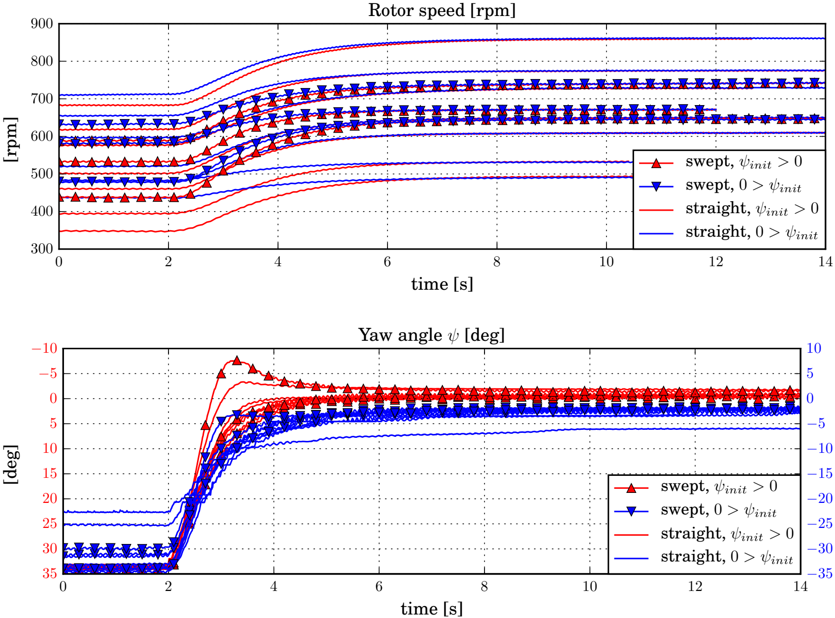
Figure: Measured applied torque and rotor speed for various electrical load settings (contour labels units are in Ohm). Based on measurements provided by the manufacturer (used with permission).

Results - Power Coefficients as Function of Yaw Angle

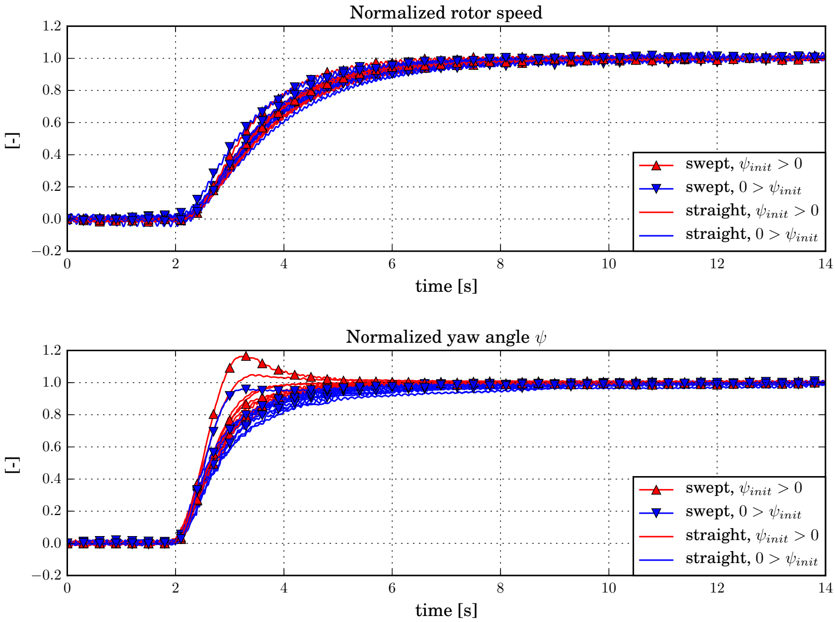


Positive yaw angle Ψ means that the blade moving upwards is closer to the wind

Results - Free Yaw Response



Results - Normalized Free Yaw Response



Open Access Data and Sources

- Documentation, Python post-processing calibration methods, plotting scripts, and representative aeroelastic beam model in HAWC2 input format: `https://github.com/davidovitch/freeyaw-ojf-wt-tests`
- Measurement results (raw and calibrated), figures and plots of the results, pictures and video's of the experiment `https://data.deic.dk/shared/62ffdf2d57c8a0133a7f3a43671d0e23`
- LaTeX sources and figures for this paper and presentation `https://github.com/davidovitch/torque2016-freeyaw-measurements/`

Conclusions

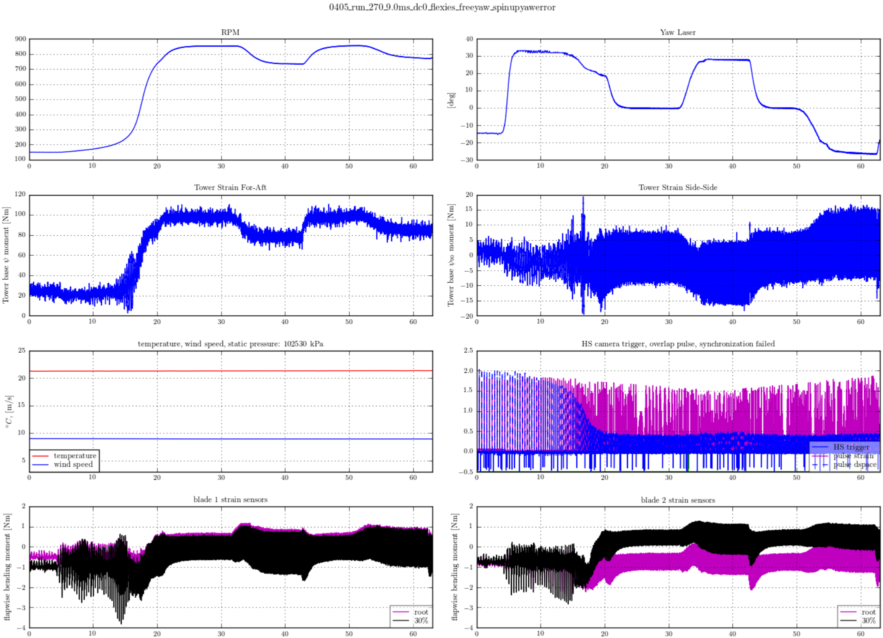
- Measurements show a stable free-yawing 3-bladed downwind turbine.
- Thrust and estimated power coefficients for various tip speed ratios and yaw angles are presented.
- Documenting and publishing data as open access is a significant effort

Future Work Recommendations

- Active rotor speed control in order to test a wider range of tip speed ratios
- Accurate power/torque measurements
- Accurate quantification of electrical losses in the system
- Qualify generator dynamics
- Yaw moment measurements
- Calibrate sensors often (> 1) and design "smart" calibration strategies
- Aerodynamic model quantification: multiple operating points at various blade pitch angle settings (requires accurate and fast pitch angle setting mechanism)
- Very flexible blades

Questions

Future work



0405_run_270_9.0ms_dc0_flexies_freeyaw_spinupyawerror
RPM
Yaw Laser
[deg]
Tower Strain For-Aft
Tower base ψ moment [Nm]
Tower Strain Side-Side
Tower base ψ90 moment [Nm]
temperature, wind speed, static pressure: 102530 kPa
°C, [m/s]
temperature
wind speed
HS camera trigger, overlap pulse, synchronization failed
HS trigger
pulse strain
pulse dspace
blade 1 strain sensors
flapwise bending moment [Nm]
root
30%
blade 2 strain sensors
flapwise bending moment [Nm]
root
30%